

CLAIMS

What is claimed is:

1 1. A movable microstructure comprising:
2 a first finger set comprising at least two first fingers extending
3 substantially parallel to a first displacement axis;
4 a second finger set comprising at least one second finger, said at least
5 one second finger extending substantially parallel to said first displacement
6 axis, terminating between two first fingers, wherein each second finger is
7 substantially closer to one of the two first fingers between which it terminates;
8 and
9 an electrical circuit providing a position-dependent force having a
10 magnitude varying in proportion to displacement along said first displacement
11 axis.

1 2. The movable microstructure of claim 1 wherein said at least two first
2 fingers comprise a conductive material, having a thickness between 2 and 100
3 microns, a width between 1 and 25 microns, a finger length between 2 to 50
4 microns, and an overlap length of more than 2 microns.

1 3. The movable microstructure of claim 2 wherein said at least one
2 second finger comprises a conductive material, having a thickness between
3 2 and 100 microns, a width between 1 and 25 microns, a finger length
4 between 2 to 50 microns, and an overlap length of more than 2 microns.

1 4. A movable microstructure comprising:
2 a substrate;
3 a proof-mass disposed above said substrate;
4 a first finger set comprising two or more first fingers affixed to said
5 substrate and extending substantially parallel to a first displacement axis
6 towards said proof-mass;
7 a second finger set comprising at least one second finger, each
8 member of the second finger set extending substantially parallel to said first
9 displacement axis from said proof-mass, terminating between two first fingers,
10 wherein each second finger is substantially closer to one of the two first
11 fingers between which it terminates, thereby forming a first capacitor; and
12 an electrical circuit providing a voltage across said capacitor to provide
13 a position-dependent force on said proof-mass, said position-dependent force
14 having a component along an axis substantially orthogonal to said first
15 displacement axis, the magnitude of said position-dependent force varying in
16 proportion to displacement along said first displacement axis.

1 5. The movable microstructure of claim 4 further including an oscillation-
2 sustaining feedback loop having an output representative of proof-mass
3 movement along said first displacement axis, said oscillation-sustaining
4 feedback loop using electrostatic forces to sustain oscillatory motion.

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1 6. The movable microstructure of claim 5 further including:
2 a capacitive bridge responsive to displacements of said proof-mass
3 along an axis orthogonal to said first displacement axis; and
4 a position sense interface connected to said capacitive bridge, said
5 position sense interface having an electrical output varying in response to
6 changes in said capacitive bridge.

1 7. The movable microstructure of claim 5 wherein the voltage applied to
2 said first capacitor is substantially constant and chosen to cause said vibrating
3 mass, absent a Coriolis force, to vibrate more precisely along said first axis.

1 8. The movable microstructure of claim 6 further including:
2 a quadrature detection circuit having an output, said quadrature
3 detection circuit synchronized with the output of said oscillation-sustaining
4 feedback loop; and
5 a feedback connection from the output of said quadrature detection
6 circuit to said first capacitor, said feedback connection providing a voltage
7 across said first capacitor;

8 wherein said voltage causes the average output of said quadrature
9 detection circuitry to converge towards a constant value, thereby causing said
10 mass to vibrate, absent a Coriolis force, more precisely along said first axis.

1 9. The movable microstructure of claim 4 further including:

2 a third finger set comprising two or more third fingers affixed to said
3 substrate and extending substantially parallel to a first displacement axis
4 towards said proof-mass; and

5 a fourth finger set comprising at least one fourth finger, each member
6 of the fourth finger set extending substantially parallel to said first
7 displacement axis from said proof-mass along a direction opposite the
8 direction of extension of said second fingers, terminating between two third
9 fingers, wherein each fourth finger is closer to one of the two third fingers
10 between which it terminates, thereby forming a second capacitor.

1 10. The moveable microstructure of claim 9 wherein said electrical circuit
2 provides a voltage across said second capacitor to provide a position-
3 dependent force on said proof-mass, said position-dependent force having a
4 component along an axis substantially orthogonal to said first displacement
5 axis, the magnitude of said position-dependent force varying in proportion to
6 displacement along said first displacement axis.

1 11. The moveable microstructure of claim 9 further including an electrical
2 circuit providing a voltage across said second capacitor to provide a position-
3 dependent force on said proof-mass, said position-dependent force having a
4 component along an axis substantially orthogonal to said first displacement
5 axis, the magnitude of said position-dependent force varying in proportion to
6 displacement along said first displacement axis.

12. The movable microstructure of claim 9 further including:

a capacitive bridge responsive to displacements of said proof-mass along a sense axis orthogonal to said first displacement axis;

a position sense interface connected to said capacitive bridge, said position sense interface having an electrical output varying in response to changes in said capacitive bridge;

a quadrature detection circuit having an output, said quadrature detection circuit synchronized with the output of said oscillation-sustaining feedback loop;

a feedback connection from the output of said quadrature detection circuit to said first and second capacitors, said feedback connection providing a defined voltage across each of said first and second capacitors, said voltage causing the average output of said quadrature detection circuitry to converge towards a constant value, thereby causing said mass to vibrate, absent a Coriolis force, more precisely along said first axis; and

a Coriolis detection circuit having an output, said Coriolis detection circuit synchronized with the output of said oscillation-sustaining feedback loop;

wherein the Coriolis detection circuit output provides an electrical signal representative of rotational motion about an axis largely orthogonal to both said sense axis and said first displacement axis.

1 13. A movable microstructure comprising:
2 a substrate;
3 a first proof-mass disposed above said substrate;
4 a second proof-mass disposed above said substrate;
5 a first finger set comprising two or more first fingers affixed to said
6 substrate and extending substantially parallel to a first displacement axis
7 towards said first proof-mass;
8 a second finger set comprising at least one second finger, each
9 member of the second finger set extending substantially parallel to said first
10 displacement axis from said first proof-mass, terminating between two first
11 fingers, wherein each second finger is closer to one of the two first fingers
12 between which it terminates, thereby forming a first smaller gap and a first
13 capacitor;
14 a third finger set comprising two or more third fingers affixed to said
15 substrate and extending in a direction opposite said first finger set and
16 substantially parallel to said first displacement axis towards said second proof-
17 mass;
18 a fourth finger set comprising at least one fourth finger, each member
19 of the fourth finger set extending substantially parallel to said first
20 displacement axis from said second proof-mass, along a direction opposite
21 said second fingers, terminating between two third fingers, wherein each
22 fourth finger is closer to one of the two third fingers between which it

23 terminates, thereby forming a second smaller gap and a second capacitor;
24 and

25 an electrical circuit providing a first voltage across said first capacitor,
26 and a second voltage across said second capacitor to provide position-
27 dependent forces on said first proof-mass and on said second proof-mass,
28 said position-dependent forces having a component along an axis
29 substantially orthogonal to said first displacement axis, the magnitude of said
30 position-dependent force varying in proportion to proof-mass displacement
31 along said first displacement axis.

1 14. The movable microstructure of claim 13 further including an oscillation-
2 sustaining feedback loop having an output representative of the relative
3 movement between said first proof-mass and said second proof-mass along
4 said first displacement axis, said oscillation-sustaining feedback loop using
5 electrostatic forces to sustain oscillatory motion.

1 15. The movable microstructure of claim 14 further including:
2 a capacitive bridge responsive to the relative displacement between
3 said first proof-mass and said second proof-mass along an axis orthogonal to
4 said first displacement axis; and
5 a position sense interface connected to said capacitive bridge, said
6 position sense interface having an electrical output varying in response to
7 changes in said capacitive bridge.

1 16. The movable microstructure of claim 14 wherein said first voltage and
2 said second voltage are distinct, are substantially constant, and are chosen to
3 cause said vibrating mass, absent a Coriolis force, to vibrate more precisely
4 along said first axis.

1 17. The movable microstructure of claim 15 further including:

2 a quadrature detection circuit having an output, said quadrature
3 detection circuit synchronized with the output of said oscillation-sustaining
4 feedback loop; and

5 a feedback connection from the output of said quadrature detection
6 circuit to said first capacitor and said second capacitor, said feedback
7 connection providing said first voltage and said second voltage;

8 wherein said first voltage and said second voltage cause the average
9 output of said quadrature detection circuitry to converge towards a constant
10 value, thereby causing said mass to vibrate, absent a Coriolis force, more
11 precisely along said first axis.

1 18. The movable microstructure of claim 14 further including:

2 a fifth finger set comprising two or more fifth fingers affixed to said
3 substrate and extending substantially parallel to a first displacement axis
4 towards said first proof-mass in the direction of said first fingers;

5 a sixth finger set comprising at least one sixth finger, each member of
6 the sixth finger set extending substantially parallel to said first displacement
7 axis from said first proof-mass along the direction of extension of said second
8 fingers, terminating between two fifth fingers, wherein each sixth finger is
9 substantially closer to the fifth finger opposite in direction of said first smaller
10 gap in relation to said second finger, thereby forming a third capacitor;

11 a seventh finger set comprising two or more seventh fingers affixed to
12 said substrate and extending substantially parallel to a first displacement axis
13 and towards said second proof-mass;

14 an eighth finger set comprising at least one eighth finger, each member
15 of the eighth finger set extending substantially parallel to said first
16 displacement axis from said second proof-mass opposite the direction of the
17 second fingers, terminating between two seventh fingers, wherein each eighth
18 finger is substantially closer to the seventh finger opposite in direction of said
19 second smaller gap in relation to said fourth finger, thereby forming a fourth
20 capacitor; and

21 an electrical circuit providing a third voltage across said third capacitor,
22 and a fourth voltage across said fourth capacitor to provide position-dependent
23 forces on said first proof-mass and on said second proof-mass, said position-
24 dependent forces having a component along an axis substantially orthogonal
25 to said first displacement axis, the magnitude of said position-dependent force
26 varying in proportion to proof-mass displacement along said first displacement
27 axis.

1 19. The movable microstructure of claim 18 further including:

2 a capacitive bridge responsive to the relative displacement between
3 said first proof-mass and said second proof-mass along an axis orthogonal to
4 said first displacement axis;

5 a position sense interface connected to said capacitive bridge, said
6 position sense interface having an electrical output varying in response to
7 changes in said capacitive bridge;

8 a quadrature detection circuit having an output, said quadrature
9 detection circuit synchronized with the output of said oscillation-sustaining
10 feedback loop;

11 a feedback connection from the output of said quadrature detection
12 circuit to said first capacitor, said second capacitor, said third capacitor and
13 said fourth capacitor, said feedback connection providing said first voltage,
14 said second voltage, said third voltage and said fourth voltage; and

15 a Coriolis detection circuit having an electrical signal output
16 representative of rotational motion about an axis largely orthogonal to both
17 said sense axis and said first displacement axis, said Coriolis detection circuit
18 synchronized with the output of said oscillation-sustaining feedback loop.

1 20. A micromachined vibratory rate gyroscope comprising:

2 a substrate;

3 a proof-mass disposed above said substrate;

4 a first finger set comprising two or more first fingers affixed to said
5 substrate and extending substantially parallel to a first displacement axis
6 towards said proof-mass;

7 a second finger set comprising at least one second finger, each
8 member of the second finger set extending substantially parallel to said first
9 displacement axis from said proof-mass, terminating between two first fingers,
10 wherein each second finger is substantially closer to one of the two first
11 fingers between which it terminates, thereby forming a capacitor;

12 an oscillation-sustaining feedback loop having an output representative
13 of proof-mass movement along said first displacement axis;

14 a capacitive bridge responsive to displacements of said proof-mass
15 along an axis orthogonal to said first displacement axis;

16 a position sense interface connected to said capacitive bridge, said
17 position sense interface having an electrical output varying in response to
18 changes in said capacitive bridge;

19 a quadrature detection circuit having an output, said quadrature
20 detection circuit synchronized with the output of said oscillation-sustaining
21 feedback loop; and

22 a feedback connection from the output of said quadrature detection
23 circuit to said capacitor, said feedback connection providing a voltage across
24 said first capacitor;

25 wherein the voltage applied to said capacitor drives the output of said
26 quadrature detection circuitry towards a constant value, thereby causing said
27 mass to vibrate absent a Coriolis force, more precisely along said first axis.

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